CHAPTER 19

Metal Contamination Affects Size-Structure and Life-History Dynamics in Isopod Field Populations

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I. INTRODUCTION

When soils become contaminated with metals, susceptible species may disappear from the area. Several field studies have documented changes in species composition among soil invertebrate fauna found around sources of metal pollution.[1] Laboratory studies have clearly demonstrated that significantly different responses to metals exists among the various invertebrate groups.[2] Change in species diversity of soil organisms may be used as an indication of serious environmental effects but, when such effects are observed, it is often too late for remedial measures. Thus, there is a need for better parameters than species abundance in ecotoxicological field studies. Demographic population attributes, such as size distribution and brood size, will respond to environmental pollution at an earlier stage. Through effects on the fitness of individual organisms in ecological time, certain combinations for reproduction and survival are selected. These combinations arise through trade-offs between different tactics (i.e., extent of investment in reproductive activity or investment in physiological adaptations) and depend on the frequency of disturbances and the general level of adversity.[3] The pattern of trade-offs, though, being constrained by available genetic variability. In a study of two populations of the freshwater isopod *Asellus aquaticus*, separated by an effluent discharge, it was shown that isopods below the discharge had a lower reproductive effort and allocated these investments into fewer and larger offspring.[4]

Demographic studies of terrestrial isopods have identified various environmental factors influencing population dynamics.[5,6] For isopods, of course, the most important factors are suitable shelter sites and availability and quality of food. Metals may be a third important factor, both as trace elements for mineral nutrition[7] and as toxic agents when present in high concentrations. The isopod *Porcellio scaber* (Latreille) is a common woodlouse inhabiting unpolluted as well as highly metal polluted sites. The species is rather resistant to metals in terms of acute toxicity, but sublethal effects on growth and reproduction have been observed under longer exposure time.[8] The presence of *Porcellio scaber* in metal polluted sites may relate to the unique ability of isopods to concentrate large amounts of metals in the hepatopancreas.[9] This continuous accumulation of metals, associated with complexation inside granules,[10] is only lethal to the isopod when a certain concentration is exceeded. For example, the lethal zinc concentration for *P. scaber* is 27 μmol g^{-1} [11] and for cadmium, the LC_{50} decreases with increasing exposure time, the ultimate LC_{50} approaches zero.[35]

As accumulation of metals results in increased mortality in older isopods, mortality may act as a selection pressure on the life-history characteristics of a population, and early maturity or increased reproduction may be favored. This presupposition is confirmed in a study performed with populations of the crustacean *Daphnia magna*; when large individuals were harvested for about ten generations, reproduction occurred at a smaller size.[12] The aim of the present study was to determine demographic patterns of a field population of *P. scaber*

Table 1. Metal Concentrations in Isopods *(Porcellio scaber)* and in the Organic Part of the Soil Profile (A-horizon) at the Two Sampling Sites. Means are Given With Standard Errors, Based on 15 Replicate Samples

	Santpoort (reference site)		Budel (smelter site)	
Metal	A-horizon ($\mu g\ g^{-1}$)	Isopods ($\mu g\ g^{-1}$)	A-horizon ($\mu g\ g^{-1}$)	Isopods ($\mu g\ g^{-1}$)
Zinc	399 ± 59	287 ± 46	864 ± 275	1347 ± 183
Cadmium	1.12 ± 0.22	6.7 ± 2.2	9.0 ± 1.1	80.9 ± 13.5
Lead	22.7 ± 4.14	6.2 ± 2.0	606 ± 93	50 ± 6.2
Copper	26.0 ± 3.2	362 ± 42	83.8 ± 7.6	250 ± 29.0

in the surroundings of a zinc smelter in Budel, the Netherlands. The population in this metal contaminated area was compared to a reference population living in a similar, but unpolluted area.

II. MATERIAL AND METHODS

The sampling site of the metal-exposed population is located approximately 1 km southeast of a zinc smelter at Budel-Dorplein, the Netherlands. The smelter has been in operation since 1892; emissions were reduced after 1974 following a change in process technology. The Budel site is a woodland consisting mainly of poplar (*Populus* spec.), birch *(Betula pendula)*, and oak *(Quercus robur)* on sandy soil. The reference site is in a similar woodland vegetation close to Santpoort, 25 km to the west of Amsterdam. Table 1 presents the metal concentrations in isopods and in the A-horizon of the soil profile; the results are based on 15 replicates. Zinc, lead, copper, and cadmium were analyzed for, using the methods described by Van Straalen and Van Wensem.[13]

Porcellio scaber Latr. populations were sampled during the years 1983 and 1984 at intervals of one month. A sample of 50 to 100 individuals was collected from shelter microhabitats, no attempt was made to estimate absolute population densities. The sample was transferred live to the laboratory in plastic pots with litter from the site.

Each individual was fresh weighed and its head width was determined using an ocular micrometer in a microscope with stereo view. Sex determination was possible for individuals with a head width larger than 0.8 mm, or heavier than 2.4 mg fresh weight, by screening the endopodites of the first and second pleopods. Animals with a head width less than 0.8 mm were not considered in the analysis. The presence of brood pouches in females was noted; the brood was removed from the pouch with forceps and counted.

III. RESULTS

Size-structure of isopods from the reference and smelter site are presented in Figures 1 and 2. The numbers of males and females in each size-class are given as a percentage of the total number sampled on each date. Although there was a clear correlation between head width and fresh weight, the latter seems to be more variable; head width is probably a better indicator of age, and was used to define population structure in Figures 1 and 2.

The populations appeared to consist of two size-groups during most of the year; occasionally, in summer (July to September), three size-groups could be discerned due to the recruitment of young adults in the population. The size frequency patterns show that *Porcellio scaber* has overlapping generations. The overlap is more pronounced in the males, which are smaller and grow more slowly than females at all stages of development. The overlap between generations seemed more pronounced in the smelter population (Figures 1 and 2) and is probably due to reduced growth in the smelter isopods. New adults entered both populations during July, August, and September.

Although head width is a good indicator of age, weight of females is a good indicator of brood size. Several studies have shown a relationship between a female's fresh weight and the number of eggs produced.[14,15] Thus, female weight is an important population dynamic characteristic which will be analyzed below.

Figure 3 shows the weight frequency distribution of the female isopods, sampled monthly and cumulated over the two sampling years at the reference and smelter sites (24 time intervals). The weight distribution of the reference population has two peaks, one peak consists of the first-year class and the second peak contains the second- and third-year classes. A similar pattern, shifted to the left, is shown for the smelter population. Clearly, the smelter females grew more slowly, which resulted in a more extensive overlap between the two generations, and a lower average weight. The mean weight of the smelter females was 20.7% in 1983 and 24.8% in 1984 less than the mean weight of the reference females.

In Figure 4 the number of females is expressed as a percentage of the total population for each month, composed of the pooled data for the corresponding months from the two sampling years. It appears that in both populations the sex ratio fluctuated throughout the year, with a total average of 55.6%. However, during spring (April, May, and June) females clearly outnumbered males in the smelter population. This can be explained by a difference in the time of main mortality: large smelter males mostly died in April and May, as also can be seen from Figure 2; while females mostly died in July, August, and December. The mortality of females hardly influences the sex ratio, as in August the new year class enters the population. This ratio is largely determined by the new year class and thus returns to 50%. From the difference in sex ratio between reference and smelter isopods in April, it can be concluded that life expectancy of male isopods is reduced at the smelter site.

With respect to reproduction, the data provide information on four parameters: (1) the period in which broods are carried, (2) the size distribution of gravid females, (3) the percentage of females participating in reproduction, and (4) the size of the brood in relation to the size of the female.

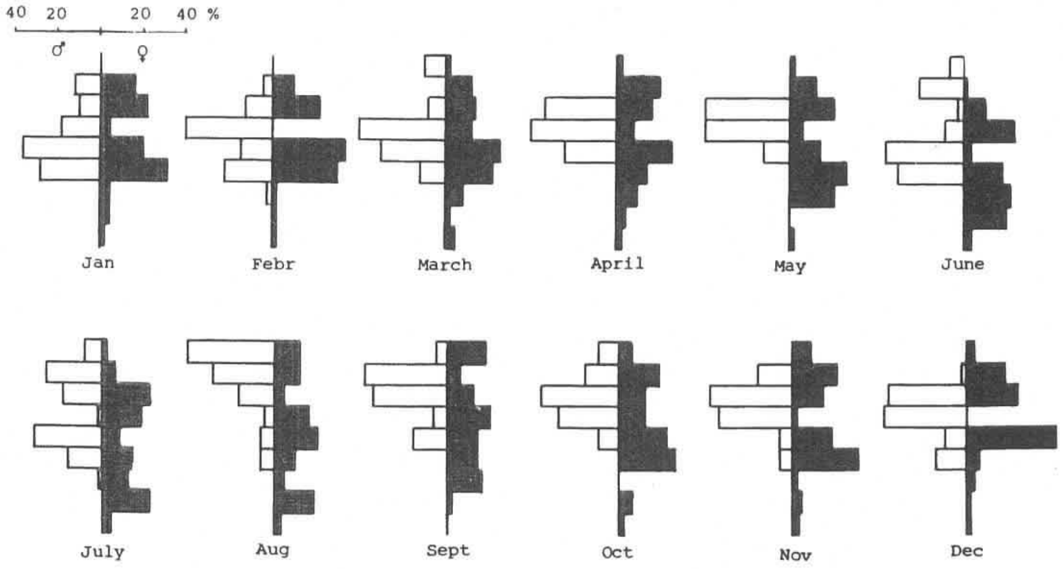
Figure 5 presents the phenology of gravid females, expressed as a percentage of the total female population collected on each sampling date. In both populations, the first females with a brood pouch were observed in March and the last ones in October. On the average, the percentage of gravid females was lower in the smelter isopods than in the reference isopods. This is mainly due to the summer period: in the reference population a second peak of reproductive females in August/September occurred, this peak was hardly present in 1983 and effectively absent in 1984 in the smelter population.

The relationship between brood size and female size was analyzed separately for the spring and the summer periods. Regression analysis produced a linear relationship between brood size and female fresh weight in all cases. The regression equations are given in Table 2. The weight dependence of brood size was more pronounced during spring; compared to the summer breeding period, summer broods were smaller. The weight of the females reproducing in August and September is about 25 mg; these are probably the females born in autumn of the previous year or in early spring. In relation to their size, smelter females produce more eggs per brood than reference females. This can also be inferred from Figure 6, which presents the time course of average brood sizes for each year separately; this figure clearly shows that, although smelter females are smaller and are less likely to reproduce during summer, their average brood size is larger both in spring and in summer.

IV. DISCUSSION

The *Porcellio scaber* population inhabiting a metal contaminated site was shown to differ from a reference population in several demographic parameters such as size distribution, sex ratio, and reproduction. In our interpretation, these differences reflect effects of cadmium and zinc, leading to advanced mortality, especially in male isopods, and to a smaller body size in both sexes. Nevertheless, the population persists through increased reproductive effort with larger broods for a given female size, this being predicted by life-history theories of Southwood[3] and Sibly and Calow.[16] Similar life-history responses have been observed in *Asellus aquaticus*,[4] in *Daphnia magna*,[12] in Collembola from contaminated sites,[17,18] and in fish.[19]

Although the differences between *Porcellio* populations have been consistent over two sampling years, and are in accordance with life-history theory, it is difficult to prove that this is causally related to increased metal levels in the litter layer. The same is true for gradient studies around a single source of pollution, where various soil factors such as pH, litter depth, and vegetation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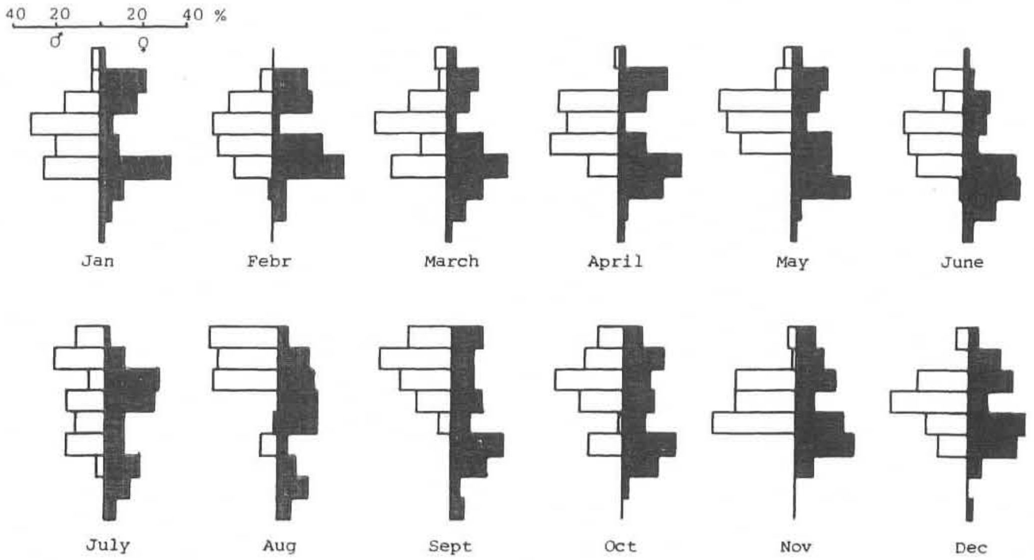
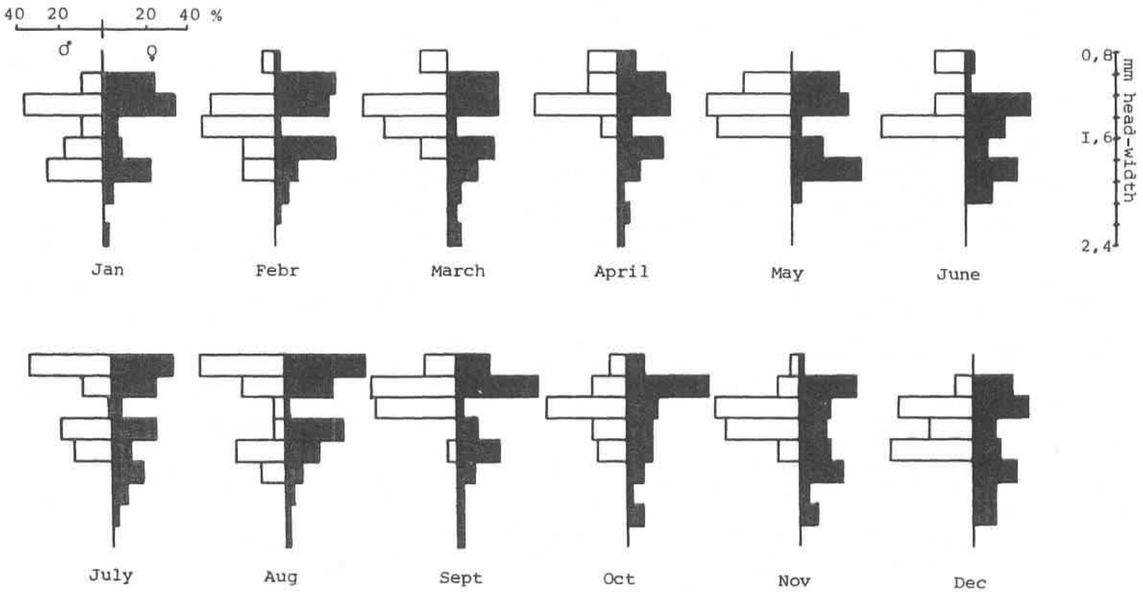


FIGURE 1. Frequency distributions for *Porcellio scaber* population structure at the reference site (Santpoort). Males (left) and females (right) are classified separately according to head width, for each monthly sampling occasion during a two-year period.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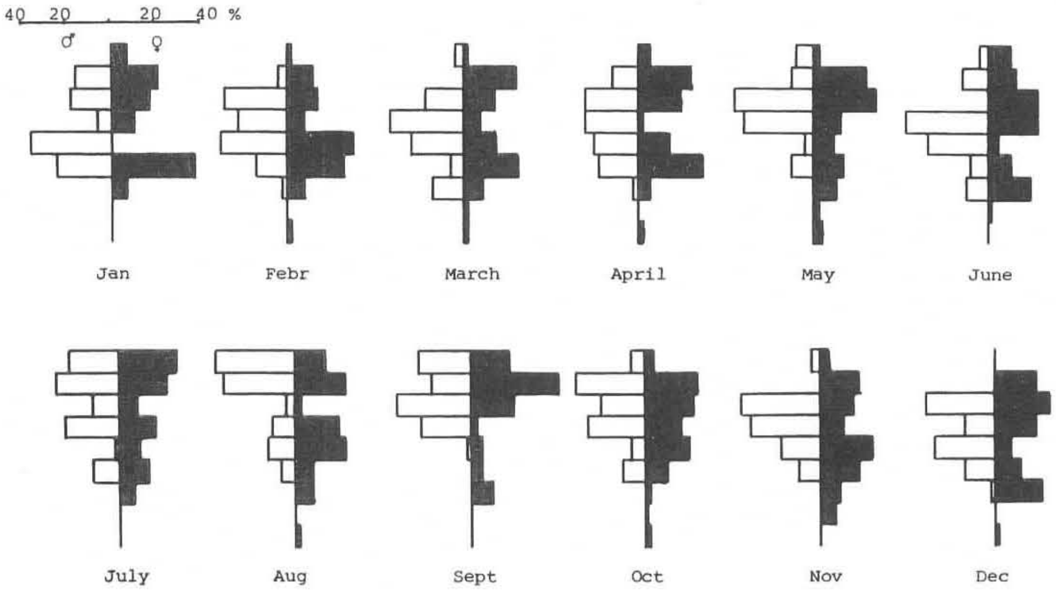

FIGURE 2. Frequency distributions for *Porcellio scaber* population structure at the smelter site (Budel). Males (left) and females (right) are classified separately according to head width, for each monthly sampling occasion during a two-year period.

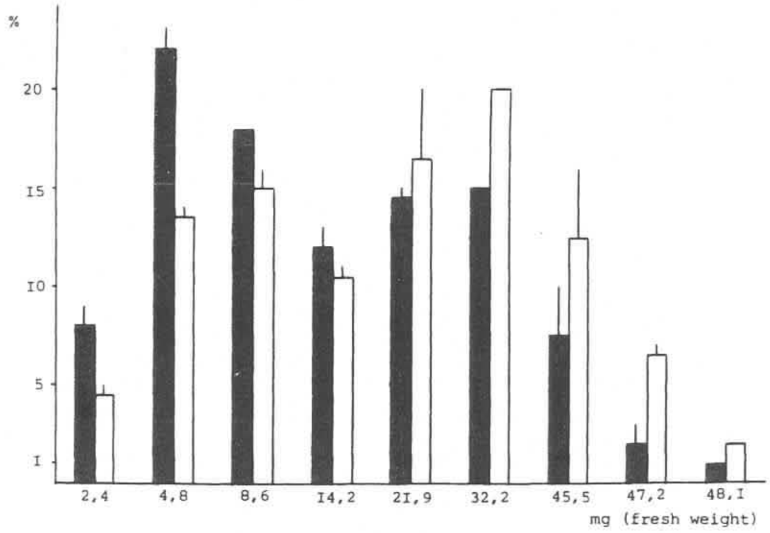

FIGURE 3. Frequency distributions of female *Porcellio scaber* at the reference site (open columns) and at the smelter site (filled columns). All females sampled monthly during a two-year period (24 times in total), were classified according to their head width. The x-axis indicates the mean weight of each head width size class and the bars represent the standard error.

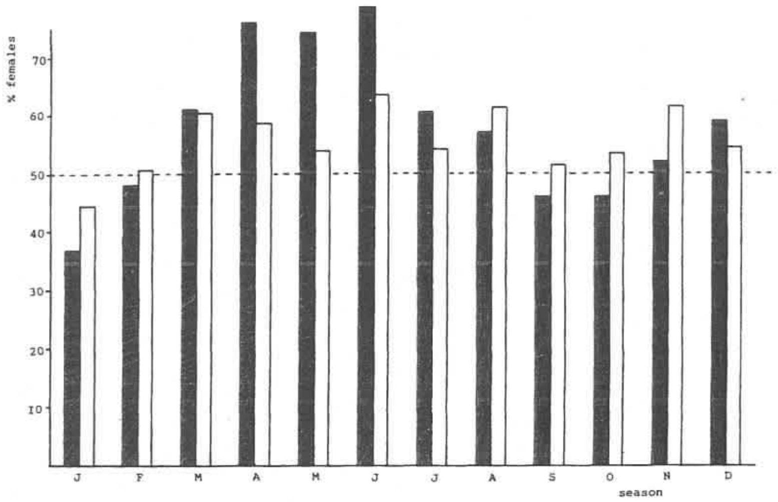

FIGURE 4. Sex ratio in two *Porcellio scaber* populations, expressed as the percentage of females in the total population. Observations from two successive years were taken together for each month. Open columns: reference population; filled columns: smelter population.

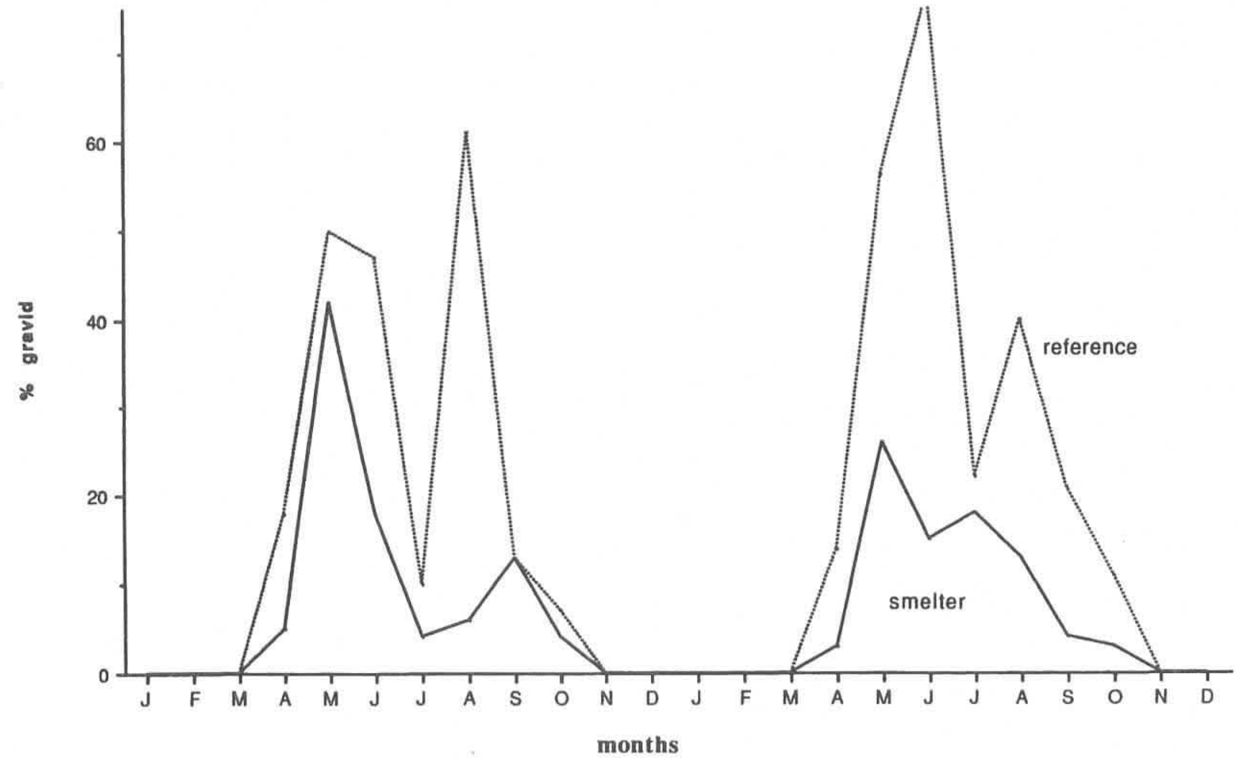

FIGURE 5. Seasonal occurrence of gravidity in *Porcellio scaber*, expressed as the percentage of gravid females in the total female population on 24 sampling occasions through a two-year period for a reference (····) and a smelter population (——).

Table 2. Relationship Between Female Fresh Weight and the Number of Eggs in the Brood Pouch, Separated For the Spring and Summer Breeding Seasons, For Two Populations of *Porcellio scaber* (w = Female Fresh Weight (mg), y = Brood Size)

	Santpoort (reference site)		Budel (smelter site)	
Season	**Equation**	**Brood size at w = 30 mg**	**Equation**	**Brood size at w = 30 mg**
Spring	$y = 13.23 + 0.720\ w$	35	$y = 16.91 + 0.895\ w$	44
Summer	$y = 6.81 + 0.319\ w$	16	$y = 15.27 + 0.468\ w$	29

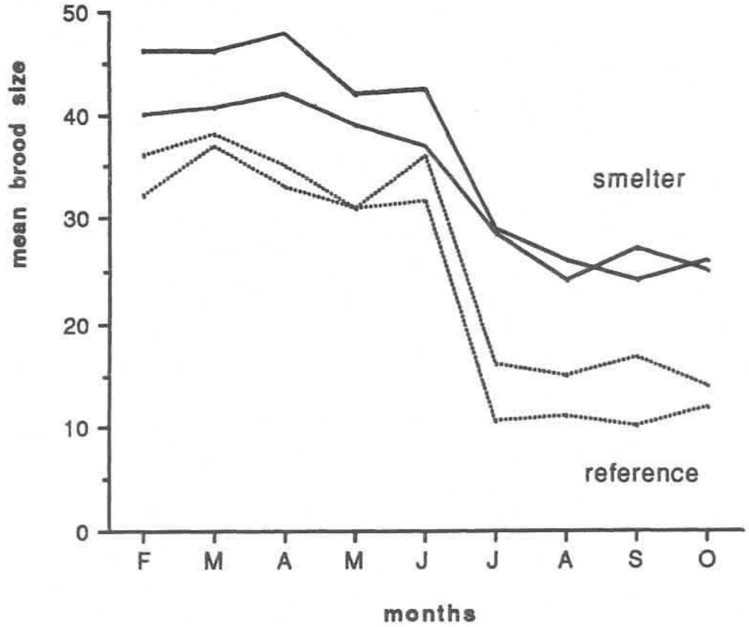

FIGURE 6. Mean brood size (number of eggs in brood pouch) for *Porcellio scaber* in relation to the season (months) during two years, for reference (····) and smelter population (——).

cover may covary with metal contamination.[20-23] In the case of *P. scaber* there is additional information available, indicating that at the smelter site the large individuals are affected by metals. Firstly, the concentration of zinc found in large isopods, especially the males, closely approaches the lethal concentration as found by Hopkin.[11,24] Secondly, the zinc concentration and to a lesser extent the cadmium concentration, are negatively correlated with survival time under starvation.[24] A third indication of metals affecting *P. scaber* at the smelter site, is suggested from the finding that increased metal concentration is accompanied by reduced energy reserves and by changes in the tissue distribution of metals.[24] Therefore, we suggest that a causal relationship does exist between the high level of metals in the litter layer, and the life-history dynamics of *P. scaber* at the smelter site.

Although the increased reproductive effort of smelter isopods can be seen as an adaptive response, the population at the smelter site is not adapted in the sense that it is less susceptible to metal intoxication. Earlier research has shown that isopods from a smelter strain have shifted their growth optimum to a higher concentration of cadmium in the food, but suffer from cadmium toxicity to the same extent as a reference population,[25] however, smelter isopods do seem to be able to reduce zinc accumulation by an increased zinc excretion efficiency and, by doing this, they retard the moment of zinc intoxication.[26]

The demography of *P. scaber* as documented in this study is comparable to other demographic studies on isopods at other sites. In the present study, *P. scaber* populations consisted mainly of two year-classes. Third year animals formed only a small fraction of the population. These findings are similar to those obtained by Brereton[27] for *P. scaber* in England, who estimated a maximum age for isopods in the field of between three and four years, but found only a few four-year-old individuals. Heeley[28] obtained similar results for the isopod *Armadillidium vulgare* in field populations in England, and Paris and Pitelka[29] estimated the longevity for *A. vulgare* from the San Francisco Bay area as three years.

Sex ratios of isopod populations seem to be rather variable. Brereton[27] suggested that male *P. scaber* do not survive as long as females; Paris and Pitelka[29] concluded the reverse with respect to *A. vulgare*, while McQueen[30] found equal survivorship for the two sexes in *Porcellio spinicornis*. It is possible that some of these interpretations result from behavioral differences between the sexes which may influence sampling efficiency, rather than diverging mortality patterns.[5]

In several isopod species mortality and reproduction are inversely related.[29,31,32] In the present study the sex ratio was found to approach unity during most of the sampling period, but in the smelter isopods the sex ratio deviated in favor of females during early spring. The reason for the disappearance of the males at that time is not known. Gere[33] showed that isopods hardly feed from January to April, followed by intensive feeding activity in spring, which will result, as a logical consequence, in a fast increase in metal concentration. As a result, perhaps, the body zinc concentration rapidly exceeds the critical level in the males, resulting in death due to zinc poisoning.[11]

Gravid females of *P. scaber* were found from March until October, which represents a longer season than that reported by Heeley[28] for *P. scaber* in England. The observations of Brereton[27] and Heeley[28] imply that *P. scaber* produces two broods per year which agrees with the present study, especially in the control population. In the smelter population few females succeeded in producing a second brood. This is most probably due to their reduced growth rate.

With respect to fertility the number of eggs was found to increase with female weight, as has been reported for other isopod studies.[29,31,32] Some authors have observed brood size to decrease under unfavorable conditions.[34] In the present study, however, brood size was larger in the smelter population, when females of equal weight were compared (Table 2). This can be seen as a trade-off between survival and reproduction in terms of life-history theory.[3] Increased mortality in older individuals of the smelter population favors investment in reproductive activity; this increase may also be due to brood size being determined by age rather than by weight. Since the smelter isopods grew more slowly, females of equal weight were of different ages, which suggests that the same relationship between brood size and female weight does hold for both smelter and reference isopods.

The work presented here shows that *P. scaber* is able to maintain a population at a highly metal polluted site, but that this population differs from a reference population in life-history characteristics. The smelter isopods respond to metal pollution not only with a smaller body size but female isopods also produced a larger number of offspring. Life-history patterns, determined in contaminated areas, are the product of selection for tolerance, as well as toxic effects on growth and reproduction. Nevertheless, analysis of demographic parameters provides a more sensitive tool for the investigation of sublethal effects of pollution, compared to studies noting only the abundance of species.

V. ABSTRACT

The presence of an organism at a metal contaminated site does not preclude that it is sublethally affected by the contamination. This study aimed to investigate sublethal effects in the terrestrial isopod *Porcellio scaber* by demographic analysis of field populations. Isopods were sampled monthly from a reference and a metal contaminated smelter site for a period of two years, and the populations were characterized on the basis of size structure, sex ratio, percentage of gravid females, and brood size. At the metal-contaminated site, isopods had a smaller body size and the percentage of gravid females was lower. Significant mortality among males was noted in spring, which caused a deviation in the sex ratio. In relation to body size, isopods at the smelter site carried larger broods. It is concluded from life-history patterns that *P. scaber* is sublethally affected at the smelter site, although the isopods are able to maintain their presence.

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